

CLAIMS

1 1. A method for etching oxide on a semiconductor substrate,
2 comprising exposing the oxide on the substrate to hydrofluoric acid vapor and
3 water vapor in a process chamber held at temperature and pressure
4 conditions that are controlled to form on the substrate no more than a sub-
5 monolayer of etch reactants and products produced by the vapor as the oxide
6 is etched by the vapor.

1 2. The method of claim 1 wherein the semiconductor substrate
2 comprises a silicon wafer and the oxide comprises silicon dioxide.

1 3. The method of claim 1 wherein the temperature and pressure
2 conditions are controlled to etch the oxide on the substrate at a rate of no
3 more than about
4 100 Å/minute.

1 4. A method for cleaning a contaminant on a semiconductor
2 substrate, comprising exposing the contaminant on the substrate to
3 hydrofluoric acid vapor and water vapor in a process chamber held at
4 temperature and pressure conditions that are controlled to form on the
5 substrate no more than a sub-monolayer of reactants and products produced
6 by the vapor as the contaminant is removed by the vapor.

1 5. A method for removing etch residue from a metal structure on a
2 semiconductor substrate, comprising exposing the residue to hydrofluoric acid
3 vapor and water vapor in a process chamber held at temperature and
4 pressure conditions that are controlled to form on the substrate no more than

5 a sub-monolayer of reactants and products produced by the vapor as the
6 residue is removed by the vapor.

1 6. A method for cleaning a metal contact region of a semiconductor
2 substrate, comprising exposing the metal contact region to hydrofluoric acid
3 vapor and water vapor in a process chamber held at temperature and
4 pressure conditions that are controlled to form on the substrate no more than
5 a sub-monolayer of reactants and products produced by the vapor as the
6 residue is removed by the vapor.

1 7. A method for etching oxide on a semiconductor substrate,
2 comprising the steps of:
3 exposing the oxide on the substrate to a stream of frozen particles; and
4 exposing the oxide on the substrate to hydrofluoric acid vapor and
5 water vapor in a process chamber held at temperature and pressure
6 conditions that are controlled to form on the substrate no more than a
7 multilayer of etch reactants and products produced by the vapor as the oxide
8 is etched by the vapor.

1 8. A method for cleaning a contaminant on a semiconductor
2 substrate, comprising the steps of:
3 exposing the contaminant on the substrate to a stream of frozen
4 particles; and
5 exposing the contaminant on the substrate to hydrofluoric acid vapor
6 and water vapor in a process chamber held at temperature and pressure
7 conditions that are controlled to form on the substrate no more than a
8 multilayer of etch reactants and products produced by the vapor as the oxide
9 is etched by the vapor.

1 9. The method of either of claims 7 or 8 wherein the process
2 chamber temperature and pressure conditions are controlled to ^{form} from on the
3 substrate no more than a saturated monolayer of etch reactants and products
4 produced by the vapor as the oxide is etched by the vapor.

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1 10. The method of either of claims 7 or 8 wherein the process
2 chamber temperature and pressure conditions are controlled to ^{form} from on the
3 substrate no more than a sub-monolayer of etch reactants and products
4 produced by the vapor as the oxide is etched by the vapor.

1 11. The method of either of claims 7 or 8 wherein the stream of
2 frozen particles comprises a stream of frozen CO₂ particles.

1 12. A method for etching oxide on a semiconductor substrate,
2 comprising the steps of:
3 producing a positive electrical charge on the oxide; and
4 exposing the oxide on the substrate to hydrofluoric acid vapor and
5 water vapor in a process chamber held at temperature and pressure
6 conditions that are controlled to form on the substrate no more than a
7 saturated monolayer of etch reactants and products produced by the vapor as
8 the oxide is etched by the vapor.

1 13. A method for etching oxide on a semiconductor substrate,
2 comprising the steps of:
3 producing a positive electrical charge on the oxide; and
4 exposing the oxide on the substrate to hydrofluoric acid vapor and
5 methanol vapor in a process chamber held at temperature and pressure

6 conditions that are controlled to form on the substrate no more than a
7 saturated monolayer of etch reactants and products produced by the vapor as
8 the oxide is etched by the vapor.

1 14. A method for etching oxide on a semiconductor substrate,
2 comprising the steps of:
3 producing a positive electrical charge on the oxide; and
4 exposing the oxide on the substrate to hydrofluoric acid vapor and
5 isopropyl alcohol vapor in a process chamber held at temperature and
6 pressure conditions that are controlled to form on the substrate no more than
7 a saturated monolayer of etch reactants and products produced by the vapor
8 as the oxide is etched by the vapor.

1 15. The method of any of claims 12, 13, or 14 wherein the process
2 chamber temperature and pressure conditions are controlled to ^{form} on the
3 substrate no more than a sub-monolayer of etch reactants and products
4 produced by the vapor as the oxide is etched by the vapor.

1 16. The method of any of claims 12, 13, or 14 wherein the positive
2 electrical charge is produced on the oxide by exposure of the oxide to an
3 electron beam.

1 17. The method of any of claims 12, 13, or 14 wherein the positive
2 electrical charge is produced on the oxide by exposure of the oxide to
3 ultraviolet light through a metallic screen.

1 18. The method of any of claims 12, 13, or 14 wherein the positive
2 electrical charge is produced on the oxide by exposure of the oxide to a

3 plasma environment wherein the substrate is biased by a negative-polarity
4 DC voltage.

1 19. A method for etching oxide on a semiconductor substrate,
2 comprising the steps of:
3 producing a negative electrical charge on the oxide; and
4 exposing the oxide on the substrate to hydrofluoric acid vapor and
5 water vapor in a process chamber held at temperature and pressure
6 conditions that are controlled to form on the substrate no more than a
7 multilayer of etch reactants and products produced by the vapor as the oxide
8 is etched by the vapor.

1 20. The method of claim 19 wherein the negative electrical charge is
2 produced on the oxide by exposure of the oxide to a plasma environment
3 wherein the wherein the substrate is biased by a RF voltage.

1 21. The method of claim 19 wherein the negative electrical charge is
2 produced on the oxide by exposure of the oxide to a plasma environment
3 wherein the substrate is biased by a positive-polarity DC voltage.

1 22. A method for etching oxide on a semiconductor substrate,
2 comprising the steps of:
3 releasing electrical charge from the oxide by exposing the oxide on the
4 substrate to a stream of frozen particles, the substrate temperature
5 remaining uncontrolled during the exposure; and
6 exposing the oxide on the substrate to hydrofluoric acid vapor and
7 water vapor in a process chamber held at temperature and pressure
8 conditions that are controlled to form on the substrate no more than a

9 multilayer of etch reactants and products produced by the vapor as the oxide
10 is etched by the vapor.

1 23. The method of claim 22 wherein the process chamber
2 temperature and pressure conditions are controlled to ~~from~~ on the substrate
3 no more than a saturated monolayer of etch reactants and products produced
4 by the vapor as the oxide is etched by the vapor.

1 24. The method of claim 20 wherein the process chamber
2 temperature and pressure conditions are controlled to ~~from~~ ^{form} on the substrate
3 no more than a sub-monolayer of etch reactants and products produced by the
4 vapor as the oxide is etched by the vapor.